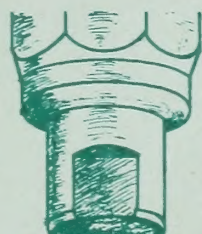


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The Drop Size Spectra Method for Estimating the Mass Median Diameter of Aerial Sprays

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INTRODUCTION

Atomizing devices produce a range of drop sizes. Because drop size influences deposit distribution, evaporation, and drift in aerial spraying, some measure of spray atomization is essential. This measure is commonly expressed as the mass median diameter (mmd)—50 percent of a spray volume is in drop sizes above mmd and 50 percent is below. Samples of the spray drops are collected on paper cards placed across the spray swath of the aircraft. The ratio of big to small drops, for a given mmd, varies with the atomizing device, speed of the aircraft, and other factors.

A simplified indirect method has been developed (Maksymiuk 1963 and 1964) for determining the mmd. By using specific conversion factors, the mmd can be derived from just the largest drop diameter in the continuous spectrum (D-max). Such factors were determined only for slow (about 80 m.p.h.) and medium speed (about 170 m.p.h.) planes with standard spray nozzles and oil-base sprays. Application of the D-max method is limited because the accuracy of these conversion factors is known only for the test conditions for which they were developed and tested. Before conversion factors can be developed for conditions where the drop size distribution may be different, the mmd must be determined from the entire drop size spectrum.

This paper reports a study to develop a method that can be used for this purpose. It incorporates some elements of the procedure for drop size sampling published by Thornton and Davis (1956).

Use of commercial names does not constitute an endorsement by the U.S. Department of Agriculture.

¹ This publication is based on work conducted as part of a cooperative project of the Division of Forest Insect Research, Forest Service, and the Agricultural Engineering Research Division, Agricultural Research Service.

DROP SIZE SAMPLING

The flow rate of the spray should be less than 0.25 gallon per acre (Potts 1958). Use of this rate reduces the chance of spray drops overlapping on the sampling surface, especially under the plane, and this rate can be obtained by removing some of the nozzles. All nozzles should be the same size, and their orifices should be oriented in the same direction. Spray pressure should not be changed.

Several kinds of cards can be used to collect samples of drop sizes. Black-dyed oil spray² can be sampled with glossy undyed Kromekote³ paper cards (4 by 5 inches). These cards will record drops down to about 7 microns in diameter (Maksymiuk and Moore 1962). Dyed Kromekote cards (White 1959) and dyed Printflex cards (Davis and Elliott 1953) can also be used. However, these cards register drops down to only about 40 and 85 microns in diameter, respectively.

About 150 of one of these types of cards are placed in a line at right angles to the anticipated flight line. They are set at 5-foot intervals for small planes (like the Stearman and Piper Cub), which produce narrow swaths, and at 10-foot intervals for large planes (like the TBM), which produce wider swaths. The cards are fastened to aluminum plates with paper clips and placed on wooden stakes so they will be above the ground vegetation. Each card represents a drop sampling station.

Upwind or crosswind flights are made. Wind speed should not exceed about 6 m.p.h. Spray

² Two pounds of Sudan Black oil-soluble dye per 50 gallons of No. 2 fuel oil. The dye is manufactured by General Dyestuff Division, General Aniline and Film Corporation, 435 Hudson Street, New York 14, N.Y. (Use of company or brand names in this paper does not imply sole endorsement of the products mentioned.)

³ Kromekote cover 65-pound glossy paper coated on one side. The paper is manufactured by Champion Paper & Fiber Co., Hamilton, Ohio.

is released from the aircraft while it is flying at a right angle to the line of cards. For small planes, the spraying height is about 50 feet; the spray is turned on about 400 feet before the sampling line is reached and turned off about 400 feet beyond it. For large planes, the spraying height is about 150 feet or more; the spray is turned on about 800 feet before reaching the sampling line and turned off at about the same distance beyond it. At the higher wind speeds (4 to 6 m.p.h.), especially when cross-wind flights are made, it may be advisable to reduce the spraying height or use a longer line of cards to prevent drifting of the spray beyond the card line.

Fifteen to 20 minutes is allowed for deposition of the drops. Then the cards, with the aluminum plates still attached, are picked up in consecutive order, and placed in wooden boxes similar to slide boxes. Two cards are placed back-to-back in each slot, and the boxes are taken to the laboratory. The cards are not sampled until the drops stop spreading; this might be 10 minutes to several hours, depending on the size of the drops and the spray material used.

PREPARATION OF CARDS FOR DROP SIZING

After the drops cease to spread, the cards are removed from the aluminum plates and numbered consecutively according to their position in the sampling line.

One square centimeter of card surface is used as a basic drop sampling unit; an electric cardmarker⁴ can be used to rapidly crosshatch the cards into squares of this size (figs. 1, 2). The cards are fed twice (horizontally and vertically) over a brass marking roller. This roller contains 13 machine-grooved sharp edges spaced at 1-centimeter intervals. An adjustable rubber roller presses the card against the brass roller, producing sharp and well-defined impressions. These impressions are permanent, and do not interfere with the visibility of even small spots. About 120 cards can be cross-hatched in 10 minutes.

GROUPING OF DROPS INTO DIFFERENT SIZE CLASSES

To determine the mmd of the drop spectrum on the cards, the drop size frequency distribution must first be known. The simplest and fastest way to do this is to group the spots into size classes. When spots from different drop size spectra were grouped into seven classes, the mean mmd was practically the same (0.8 percent higher, range 0.2 percent) as the mean of the ungrouped data.

⁴ Cardmarker made by Harold Mabry, formerly employed at this laboratory.

The width of the drop size spectrum varies directly with the degree of spray atomization (Maksymiuk 1963); therefore, to divide a given spectrum into seven classes, the classes must be wider for coarse sprays than for fine ones. Microscope eyepiece reticles have been designed for sizing the spots on the cards directly into seven classes (fig. 3). The reticles were made with deltas of 200, 300, 400, 500, 600, and 700 microns. The classes are numbered to permit convenient recording of the number of spots in each class. The inside diameters of the circles represent the upper class boundaries. Spot diameters that are smaller than the smallest circle fall in the first class; spot diameters that are larger than the smallest circle but smaller than the second largest one fall in the second class, etc.

These circular reticles have the following advantages over line reticles: (1) The spots can be sized faster, (2) there is less eye fatigue, and (3) spots that are not round can be readily sized without measuring and averaging the shortest and longest diameters.

Reticles can be made directly on film by photographically reproducing figure 3 or enlarged scale drawings of the circles shown. Direct positive film is used in a camera with a ground glass viewer. The size of the image of the largest circle can be readily checked with a standard crossline eyepiece reticle (one division = 100 microns) and a magnifier. The camera is moved back and forth until the proper magnification is obtained. For example, to reproduce the circles with a delta of 300 microns, the image of the largest circle should be 2,100 microns in inside diameter. The reticles can be cut from the developed film. Each reticle is then checked under a microscope to be sure the proper size was obtained.

To select the reticle for any drop spectrum, the diameter of the largest spot in the continuous spectrum (D_{max}) is divided by seven. The quotient is the delta number. To determine the spot D_{max} , the total surface area of all cards is examined, the five largest spots are identified, and their diameters are measured to the nearest 100 microns. These diameter measurements are then tabulated in order of decreasing size. The spot D_{max} is the largest one with not more than 200 microns difference between it and the one next largest to it going from the smallest spot size up. For example, for spot diameters of 3,600, 3,500, 2,100, 2,000, and 1,900, the spot D_{max} is 2,100 microns. Thus, a 300-delta reticle would be used.

Spots with diameters larger than D_{max} are occasionally found. These can be ignored because experience has shown that their inclusion in the measurements left the mmd virtually unchanged.

To use a reticle, it is inserted in a 10X or 12X eyepiece of a binocular dissecting micro-

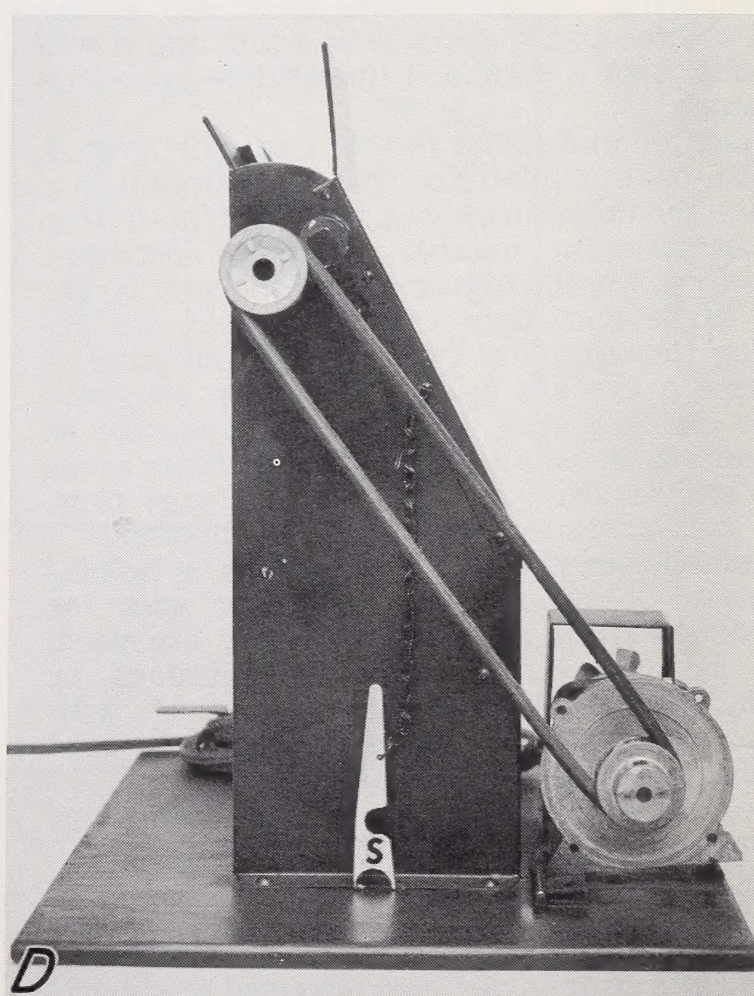
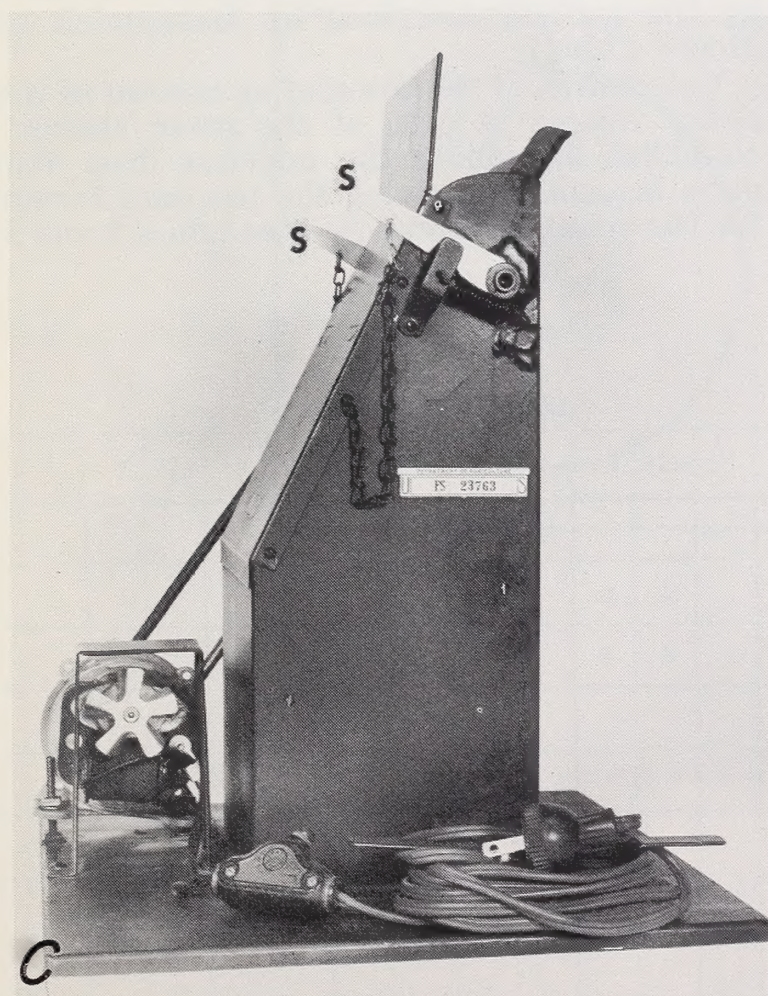
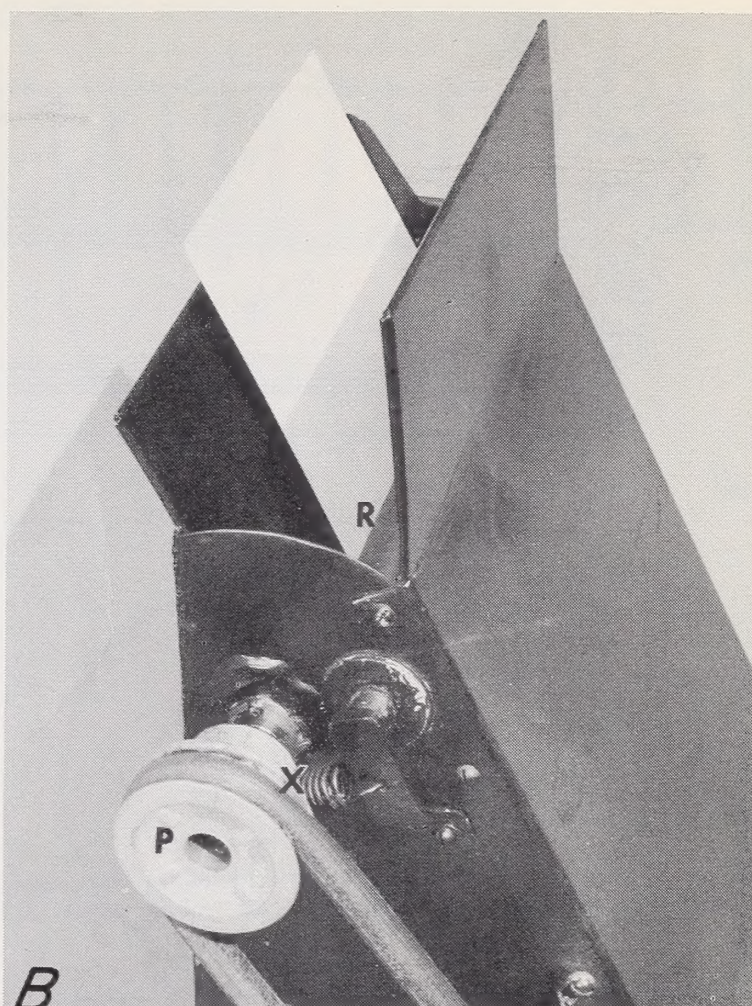
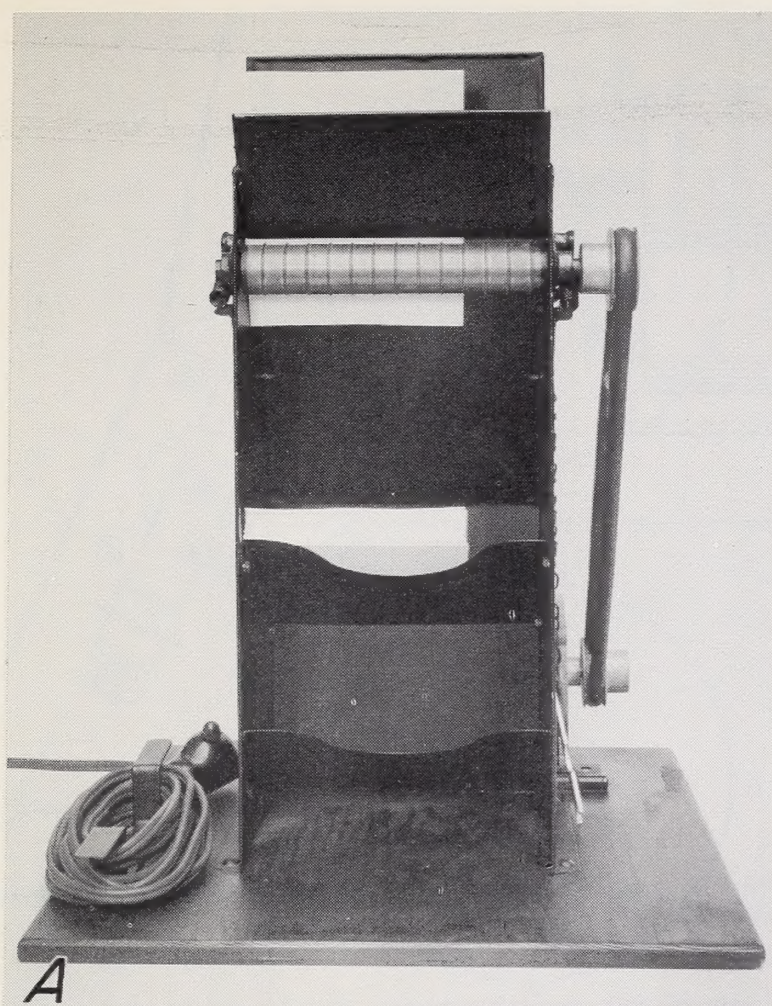


Figure 1.—A, Front view of cardmarker used for crosshatching card surface; B, upper right view showing pulley (P) attached to brass roller, rubber roller (R), and spring (X) to keep tension between the rollers when marking cards; C, left side view showing spacers (S) inserted between brass axes and rubber rollers to release tension when the marker is not in use; D, right side view showing motor assembly and spacer (S).

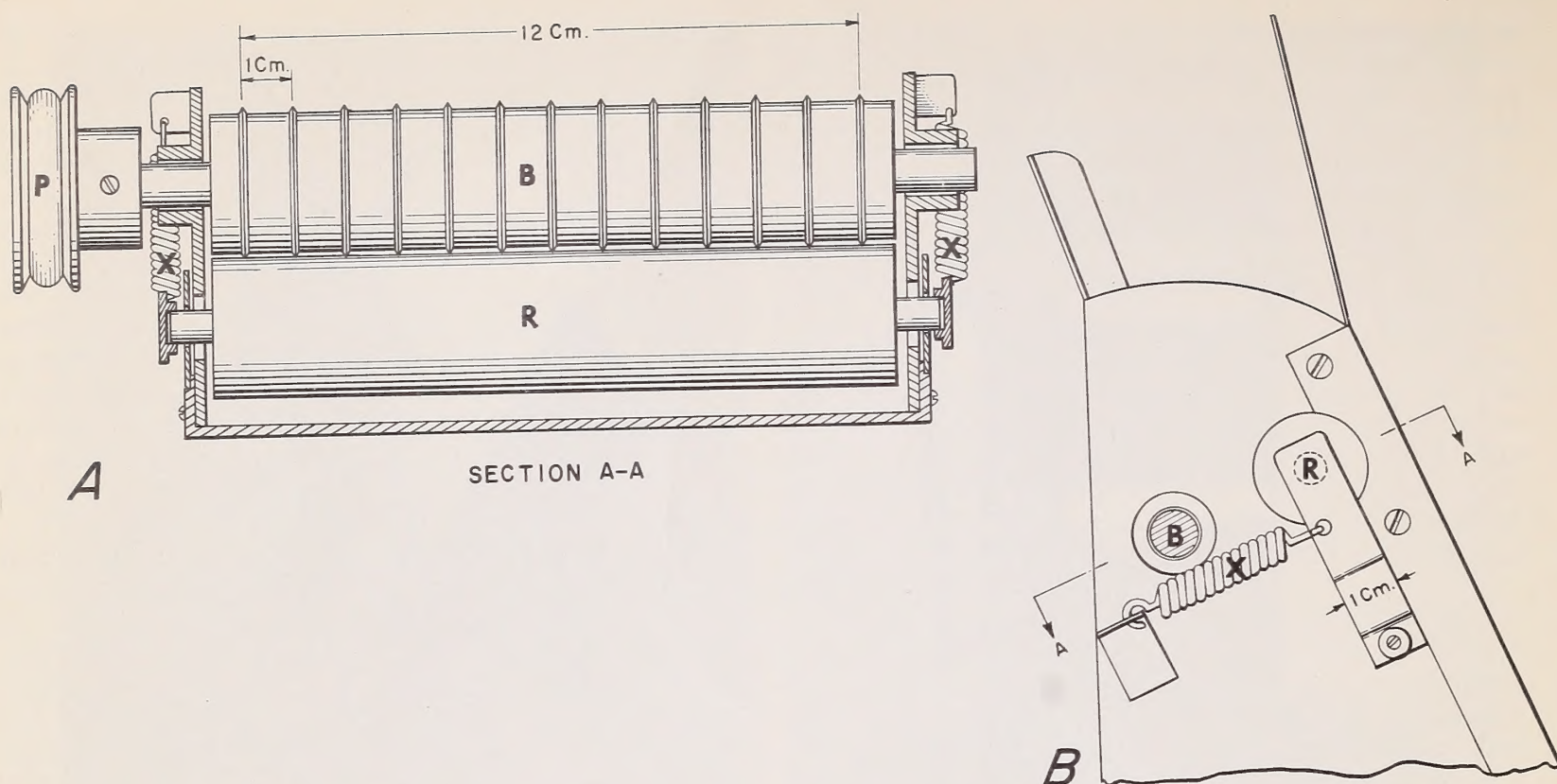


Figure 2.—A, Back view of brass roller (B) with pulley (P), rubber roller (R), and two springs (X); B, upper left side view of cardmarker showing relative position of brass roller (B), rubber roller (R), and spring (X).

scope equipped with a 1X objective. A properly positioned reticle will be magnified to the same degree as the spots to be sized, and it will coincide with a standard line reticle placed on the stage.

Thornton and Davis (1956) and Hurtig et al. (1956) have pointed out that the sampling intensity should be increased with increased drop size because the number of drops decreases. Therefore, for the higher class numbers, larger card areas and more cards are used for obtaining the drop size frequency distribution.

Three areas are selected for drop size estimates on each card (fig. 4), and these are at the same place on all cards. Each of these areas is 2 squares wide and 8 squares long; thus, each area contains 16 square centimeters.

A plastic template (4 by 5 inches) is helpful for rapid location of the sampling area for each of the three estimates. As they are sized, spots are marked to prevent omissions or double tallies. A laboratory counter,⁵ with seven or more keys, can be conveniently used to count the spots in each class.

The procedure for making these drop size estimates is given in table 1.

CALCULATION OF SPRAY VOLUME

The class boundaries are converted to spherical drop sizes. This is done by dividing the spot diameters by an appropriate spread factor (table 2). Spread factors, which vary with the

drop size and the spray used, can be determined by the method described by Maksymiuk and Moore (1962).

Calculation of the cumulative percent of total spray volume in each of the seven classes is simplified by cubing the midclass drop diameters instead of applying the standard formula for the volume of a sphere (see tables 2 and 3).

	EST. 1			EST. 2			EST. 3		
	A	B							
	C	D							
				A	B				
				C	D				
							A	B	
							C	D	

Figure 4.—Location of sampling units on a spray assessment card.

⁵ Clay Adams, Incorporated, New York, N.Y.

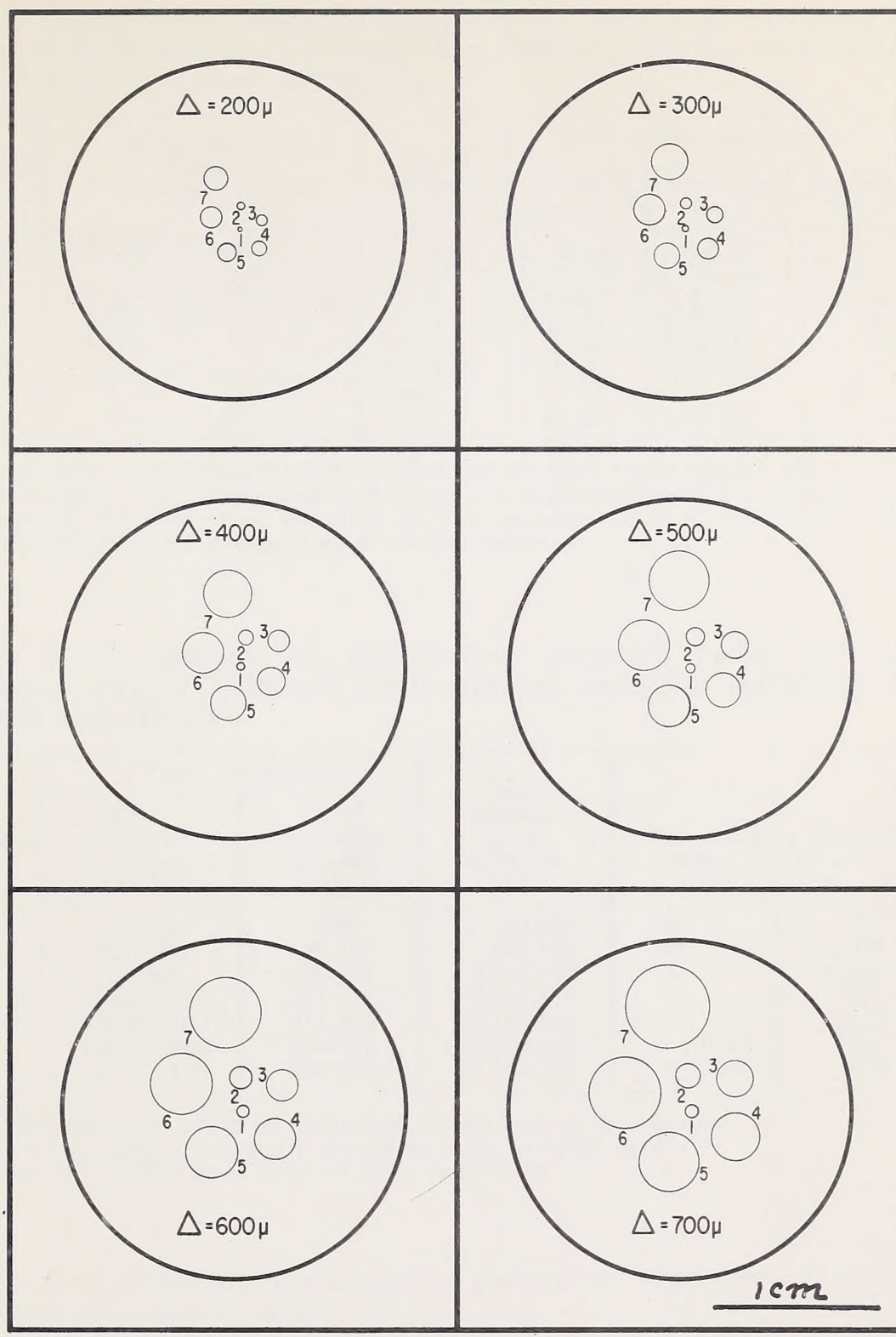


Figure 3.—Microscope eyepiece circular reticles for sizing of spot diameters on cards into seven classes; class width in microns is indicated by delta.

Table 1.—The drop sampling frequency for each drop size class, the squares to be sampled for each class number, and the card number sampled for each mmd estimate ¹

Class No.	Drop sampling frequency (1 square centimeter per card)	Squares sampled	Card No. sampled for		
			Estimate No. 1	Estimate No. 2	Estimate No. 3
1	Every 16th card -----	A	1, 17, etc.	6, 22, etc.	11, 27, etc.
2	Do -----	A	1, 17, etc.	6, 22, etc.	11, 27, etc.
3	Every 4th card -----	A	1, 5, etc.	2, 6, etc.	3, 7, etc.
4	Each card -----	A	1, 2, etc.	1, 2, etc.	1, 2, etc.
5	Do -----	A	1, 2, etc.	1, 2, etc.	1, 2, etc.
6	Do -----	A, B, C, and D	1, 2, etc.	1, 2, etc.	1, 2, etc.
7	Do -----	All 16	1, 2, etc.	1, 2, etc.	1, 2, etc.

¹ Note that different cards are sampled for the first three classes, but all cards are sampled in the fourth class and above. All spots on square A are sized. Spots falling into the sixth class are sized on four squares (A, B, C, D). Spots falling into the seventh class are sized on all sixteen squares.

Table 2.—Calculation for determining weighted factor for drop sampling unit of 1 square centimeter per sampling station by 300 micron spot classes ¹

Class No.	Class boundaries		Drop midclass cubed, microns (C)	Sampling factor ² (D)	Weight ³ (E = C X D)
	Spot diameter, microns (A)	Drop diameter, microns (B)			
1	25-300	7-67	50,653	16	81
2	300-600	67-128	941,192	16	1,506
3	600-900	128-171	3,375,000	4	1,350
4	900-1,200	171-211	6,967,871	1	697
5	1,200-1,500	211-250	12,167,000	1	1,217
6	1,500-1,800	250-290	19,683,000	.2500	492
7	1,800-2,100	290-332	30,080,231	.0625	188

¹ Black-dyed No. 2 fuel oil on undyed Kromekote cards was used.

² Based on number of square centimeters per sampled card.

³ Last four places were dropped off in each class.

Table 3.—Calculation of cumulative percent of total spray volume in different drop size classes ¹

Class No.	Weight (E)	Number drops based on three estimates (F)	(G = E X F)	Total volume, cumulative percent (H)	Upper class boundary, microns (I)
1	81	51	4,131	3.05	67
2	1,506	20	30,120	25.25	128
3	1,350	32	43,200	57.10	171
4	697	47	32,759	81.25	211
5	1,217	14	17,038	83.81	250
6	492	14	6,888	98.89	290
7	188	8	1,504	100.00	332
			135,640		

¹ An example from an actual flight is given in table 3. The G column is obtained by multiplying the weight times the number of drops. The percent volume in each class is computed by multiplying the reciprocal of the total of G column by the G value for each class and by 100 (not shown in table 3). Then the cumulative percent of total spray volume at each class is obtained. This is used to calculate the mmd.

Since the sampling frequency for each drop size class varies, a weighted sampling factor must be determined. This is done in one of two ways: The drop sampling factor (table 2) is multiplied by the drop midclass cubed or by the number of drops in each class. It is time-saving to multiply the drop sampling factor by the midclass cubed to obtain a weighted sampling factor. This computed weight (table 2) is rounded by cutting off the last four places in all classes. This speeds up the spray volume computations without affecting their accuracy.

CALCULATION OF MASS MEDIAN DIAMETER

The mmd can be calculated arithmetically, using the following formula (all percentages are cumulative percents of the total spray volume).

$$\text{mmd} = a + \left[\frac{b - c}{d - c} (e - a) \right]$$

where a=upper class boundary below 50 percent;

b=50 percent;

c=volume at upper class boundary below 50 percent;

d=volume at upper class boundary above 50 percent;

e=upper class boundary above 50 percent.

Substituting the data from table 3 for the above formula, the mmd is as follows:

$$\text{mmd} = 128 + \left[\frac{50 - 25.25}{57.10 - 25.25} (171 - 128) \right] = 161 \text{ microns}$$

Also, mmd (and other percentiles) can be readily determined graphically by plotting the diameter of the upper class boundary over the cumulative percent of total spray volume on logarithmic probability paper (fig. 5). The mmd is the drop diameter at 50 percent of the total cumulative spray volume. It is usually the same as the mmd calculated arithmetically; in this instance it is 161 microns.

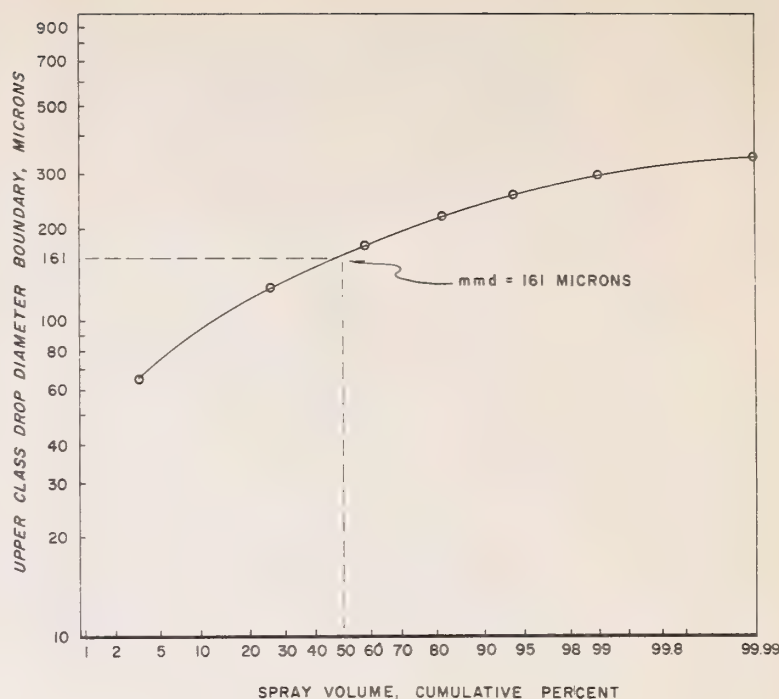


Figure 5.—Graphical determination of the mass median diameter.

PRECISION OF MMD ESTIMATES

The data from 41 series of three test flights each were analyzed to determine the precision in estimating mmd's over a wide range of spray atomization. Each series consisted of replicate flights in which the same spray equipment was used. For most series of flights, the spray equipment was manipulated to produce different degrees of atomization. Mmd's were estimated for each flight.

The mmd's for these 41 series ranged from 84 to 264 microns. The standard error of the mean estimate of each series, calculated at the 5 percent probability level and expressed as a percent of the mean, ranged from ± 1.9 to ± 9.0 percent. The mean error was ± 5.3 percent.

Moore et al. (1964) found a similar variation of mmd's among individual test flights. This variation was significantly greater than that among the three estimates for individual test flights. Therefore, to increase the precision of the mmd estimates, a mean of several test flights should be used.

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1964. The drop size spectra method for estimating the mass median diameter of aerial sprays. Forest Insect Lab., Beltsville, Md. 11 pp., illus. (U.S. Forest Serv. Res. Paper WO-1)

The mass median diameter of aerial sprays is determined from samples of different drop sizes taken at regular intervals across the aircraft spray swath. Glossy undyed Kromekote paper cards and black-dyed oil sprays are used to sample drops down to 7 microns in diameter. An electric card marker was developed for rapid ruling of sprayed cards into drop sampling units of 1 square centimeter.

Special microscope eyepiece reticles were designed for rapid and convenient sizing of drops into broad classes. The cumulative percentage of total spray volume is calculated for each class. The mass median diameter is the drop diameter at 50 percent of this volume.

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